Optimal Combining Data for Improving Ocean Modeling

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LONG-TERM GOALS

The long range scientific goals of the proposed research comprise: (1) developing rigorous approaches to optimal combining satellite and drifter data with output of regional circulation models for accurate estimating the upper ocean velocity field and mixing characteristics such as relative dispersion and finite size Lyapunov exponent, (2) constructing and comprehensive testing computationally efficient estimation algorithms based on alternative parameterizations of uncertainty (3) processing real data in the Adriatic and Ligurian Sea (MREA coastal experiments) via new techniques

OBJECTIVES

The objectives for the first year of research were:
- Implementing and comprehensive testing the fusion method developed by PI for computing surface velocities [1] in a high resolution circulation model with realistic observation characteristics
- Application of the above method for filling gaps in HF radar measurements
- Developing fusion methods based on the fuzzy logic [2,3] for estimating Lagrangian characteristics such as absolute and relative dispersion.
- Testing the Lagrangian prediction algorithms developed by PI [4,5] on a real velocity field obtained by HF radar.

APPROACH

We develop theoretical approaches to the data fusion problem in context of the possibility theory (fuzzy logic) and in the framework of the classical theory of random processes and fields covered by stochastic partial differential equations. We also design computational algorithms derived from the theoretical findings. A significant part of the algorithm validation is their testing via stochastic simulations. Such an approach provides us with an accurate error analysis. Together with my collaborators from Rosenstiel School of Marine and Atmospheric Research (RSMAS), Consiglio Nazionale delle Ricerche (ISMAR, LaSpezia, Italy), Naval Research Laboratory (Stennis Space Center, Mississippi), ENEA (Rome, Italy), Koc University (Istanbul, Turkey) we implement the algorithms in concrete ocean models such as QG, MICOM , NCOM, and MFS, as well as carry out statistical analysis of real data sets by means of new methods.

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WORK COMPLETED

1. Implementing and testing the fusion method for computing surface velocities .

The method of fusing tracer observations and model outputs for computing surface velocities developed in [1] was implemented and tested in the framework of the twin experiment approach. Synthetic data from realistic velocity outputs produced by the operational Mediterranean Forecasting System (MFS) were used, [6]. The method allows to estimate a velocity field at each time moment using two consecutive tracer snapshots.

The focus was on, first, examining realistic time intervals between snapshots and, second, processing partial tracer observations. The considered configuration consisted of a tracer patch released and advected by the current. An extensive set of experiments have been performed, and the method performance have been quantified in terms of improvement in error with respect to the model.

Further tests have been performed varying the parameters of the patch, such as width and concentration cutoff. The goal was to investigate the deviation from the purely advective evolution introducing a high numerical diffusivity.

Finally, the method was tested on synthetic data for fusing HF radar data and tracer observations.

2. Developing fusion methods based on the fuzzy logic for estimating Lagrangian trajectories .

We have suggested an approach to combining observations of a conservative tracer and modeled Lagrangian trajectories to improve the latter, [7]. The idea behind the approach is to construct an estimate of a particle position which carries the same tracer concentration as a real particle does and which is closest in a sense to the corresponding background particle. If the 'closeness' is measured in the coordinates, then we arrive at so called the Lagrangian estimate (L-estimate). On the other hand if the difference between the velocities is minimized, then the corresponding estimate is named the E-estimate (Eulerian estimate). A comprehensive comparison of these two estimates on synthetic velocity fields have been conducted which gave an unconditional preference to the E-estimate.

Then the E-estimate was used to compute the absolute and relative dispersion in the gyre superimposed by a periodic or stochastic flows. We used the space averaging in computing the dispersion even though the background flow was strongly inhomogeneous. Such an approach was justified by the fact that in reality no other ways of averaging are possible.

Experiments encompassed a wide range of parameters, such the gyre radius, intensity and density of eddies, position and initial size of the tracer patch.

3. Testing the Lagrangian prediction algorithms a velocity field obtained by HF radar.

A velocity field obtained from the ocean surface by high-frequency radar near the Florida coast was used to test Lagrangian prediction algorithms designed to evaluate the position of a particle given its initial position and observations of several other particles released at the same time. The prediction skill is essentially determined by temporal and spatial covariances of the underlying velocity field. For this reason correlation analysis of both Lagrangian and Eulerian velocities has been carried out as well.

RESULTS

1. The performance of the method has been quantified considering the improvement ($Gain$) of the estimated fields with respect to the model fields.

First, we found that in the ideal cases when the complete concentration is observed over the whole region with short time intervals Dt_{obs} of the order of 1-2 hours, the $Gain$ reached values of 80-90% for the concentration and 50-60% for the velocity, which were close to the theoretical values for perfect data.

Then, in the more realistic cases of limited observations and longer Dt_{obs} of the order of days, the *Gain* reduced. Various release points and two different velocity configurations have been considered, and the mean and std of *Gain* have been computed for Dt_{obs}=1day. The variability was found to be quite high, depending primarily on the initial position of the patch within the velocity field, which in turns determines the relative size of the cross and along gradient components of velocity and the patch advective path during Dt_{obs}. The mean of *Gain* for observations limited to high values of concentration inside the patch reached values around 30-40% for both concentration and velocity.
Finally, when only the boundary of the patch was observed, the *Gain* further reduced, even though it maintains significant with values of 15-20% for velocity and concentration. Fig.1 illustrates one of the experiments.

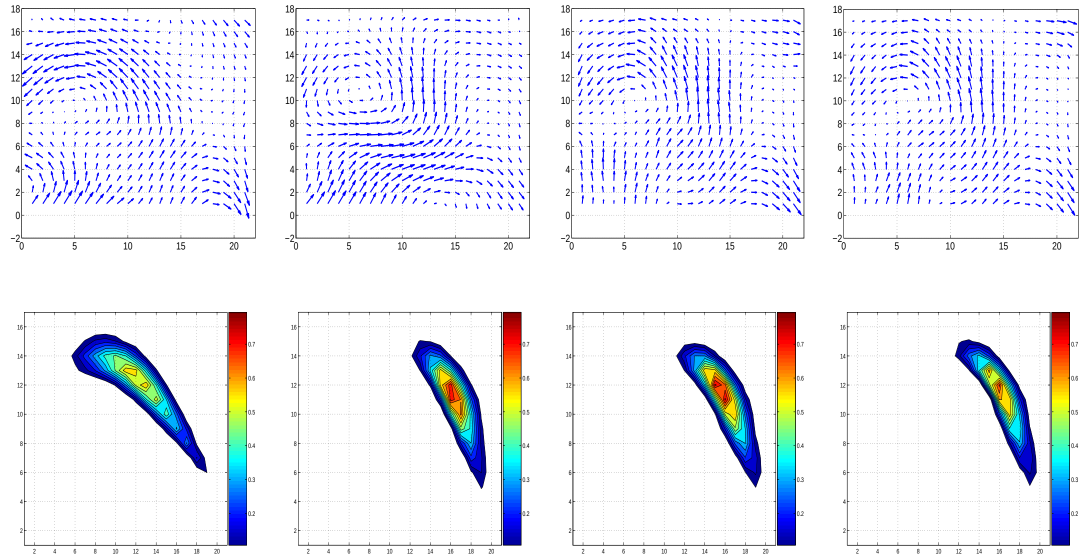


Figure 1. Top panel from left to right: 1) background velocity, 2) 'true' velocity, 2) estimate with Dt_{obs} =0.1 day, 4) estimate with Dt_{obs} =0.25 day. Bottom panel: 1) tracer advected by background, 2) tracer advected by 'real', 3) estimated tracer with Dt_{obs} =0.1 day, 4) estimated tracer with Dt_{obs} =0.25 day

One of the most important findings is that the results appear consistent when varying different parameters of the patch, such as width and concentration cutoff, thereby proving that the method is robust. In particular, the results with high diffusivity suggest that the method is applicable to realistic processes where dissipation might play an important role.
In summary, the results proved to be pretty promising, indicating the potential of the method for a number of practical applications. Also, they provided some indications on sampling and possible strategies for satellite or other remote sensing information. As an example the results show that observations of tracer gradients inside the patch can lead to a significant improvement with respect to observation of the boundary only . In the former, reducing Dt_{obs} to values of order of 0.5 days can lead to a significant improvement. For the latter, on the other hand, decreasing Dt_{obs} is not very effective.
A first try to implement the method for fusing radar and satellite data is illustrated in Fig.2. The right radar was artificially broken and then the true velocity field was retrieved from its distorted measurements and tracer observations.
2. First, we found that the developed E-estimate is much more efficient than another suggested

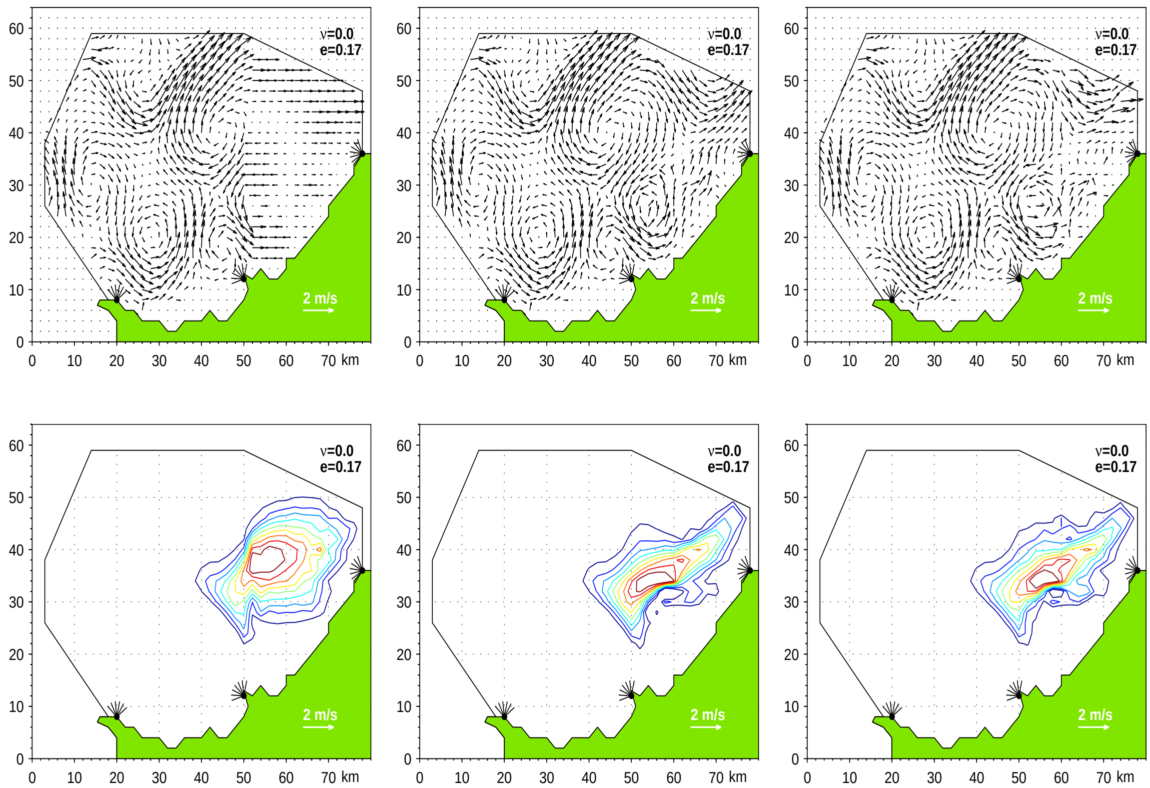


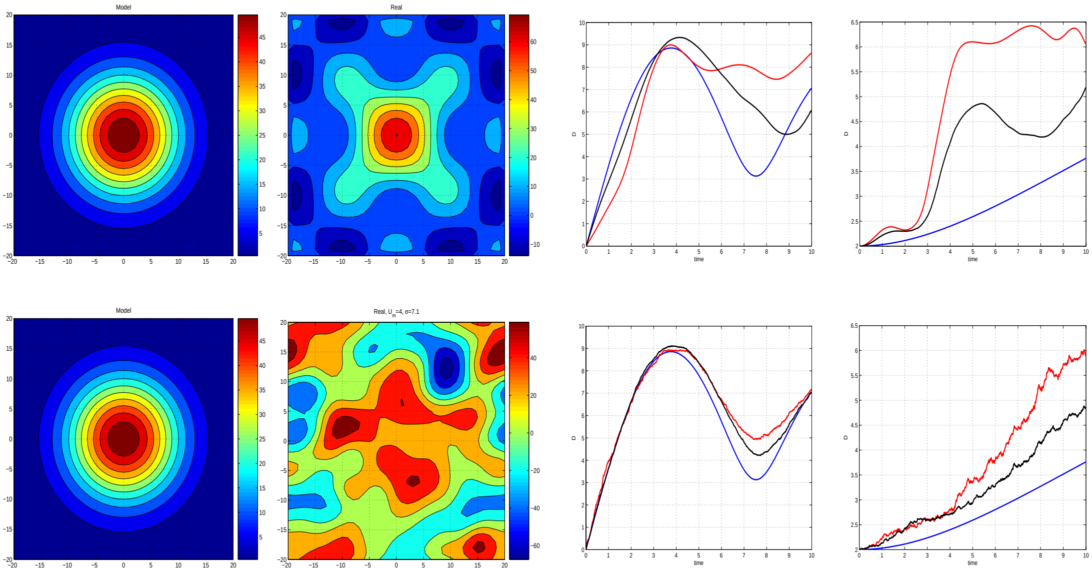
Figure 2. Top panel from left to right: 1) distorted velocity (background), 2) 'true' velocity, 3) estimate. Bottom panel: 1) tracer advected by background, 2) tracer advected by 'real', 3) estimated tracer

tool, the L-estimate, even though the latter a priori looked more attractive since it was based on the minimization of the distance from the background particle position. Especially, the advantage of the E-estimate was observed in the case of unsteady 'true' flow.

Then, the improvement achieved by using the E-estimate comparatively to the background turned out to be in the range $10\% - 34\%$ depending on the flow characteristics. This is certainly significant figures since the problem of predicting Lagrangian trajectories is very difficult and even accurate enough estimates of the underlying Eulerian velocities not necessarily lead to so good Lagrangian estimates.

Finally, the most important finding in this field, is that the proposed E-estimate happened to be highly efficient when computing the absolute (AD) and relative (RD) dispersion. In particular, the estimates of RD turned out to be very accurate and significantly improve the background RD in all the experiments. At the same time the AD estimates were not so good, but still yielded an improvement for most of time moments. One of the possible reasons is that RD is mostly determined by velocity fluctuations while AD strongly depends on the background flow. Fig. 3 illustrates the obtained results for periodic and stochastic flows.

3. Numerous experiments with releasing synthetic particle clusters in the real velocity field under investigation proved that the regression prediction method developed in [5] is more stable and reliable than the Kalman filter procedure suggested in [4]. At the same time the accuracy of both are close on scales comparable with the velocity correlation time.



Top panel from left to right: 1) background stream function, 2) 'true' stream function which is obtained by superposing a periodic system of unsteady eddies, 3) AD: background (blue), 'true' (red), estimate (black), 4) the same for RD. Bottom panel: the same when the 'true' field is obtained by superposing stochastic perturbations

IMPACT/APPLICATIONS

The developed data/model fusion methods are highly portable and computationally efficient, making them very valuable in the framework of operational strategies for rapid assessment and quick response. They have therefore some significant advantages with respect to other techniques requiring complete assimilation of the tracer information in the dynamical velocity models. These techniques, even though more powerful, require significant coding and computational time and they have to be set up in advance for the specific operational model in use. Thus, we expect that our results will stimulate more efforts in developing fusion methods which carry no risk of ruining a model during the running time and , in addition, are well theoretically founded.
As for applications, both methods contribute to a variety of practical environmental and operational issues such as monitoring and forecasting pollutant spreading, search and rescue operations in the sea, and prediction of fish larvae.

TRANSITIONS

The developed velocity fusion algorithm was used in RSMAS and ENEA (La Spezia, Italy) to test it in the operational Mediterranean Forecasting System (MFS).

RELATED PROJECTS

1. "Predictability of Particle Trajectories in the Ocean", ONR, PI T.Ozgokmen , RSMAS, N00014-05-1-0095
2. "Lagrangian turbulence and transport in semi-enclosed basins and coastal regions", ONR, PI A Griffa, RSMAS, N00014-05-1-0094

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8. M. Caglar, T.Bilal, L.I. Piterbarg, (2009), Lagrangian prediction and correlation analysis with Eulerian data, *Turkish J. Earth Sciences*, submitted

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